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CRYOGENIC SOURCE AND IONIZER FOR A BEAM OF POLARIZED DEUTERONS

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Криогенный источник и ионизатор
для получения пучка поляризованных дейтронов

Описывается криогенный источник и ионизатор для получения поляризованного пучка дейтронов на синхрофазотроне. Источник такого типа может быть также использован в качестве струйной поляризованной мишени для работ на внутреннем пучке ускорителя.

Диссоциация дейтерия в источнике ведется при низких температурах. Откачка газа при формировании атомарного пучка осуществляется с помощью крионасосов. Для пространственного разделения атомов по состояниям сверхтонкой структуры используется сверхпроводящий шестиполюсный магнит с полем 1,0 Т.

Ионизация атомарного пучка производится в ионизаторе Пеннинга в магнитном поле до 7 Т. Источник работает в импульсном режиме с Δt = 50 ÷ 100 мс и частотой следования импульсов 5 ÷ 7 с.

Испытания установки проводились по 2-3 недели без сублимации дейтерия. Для обеспечения ее работы требовалось 200 л жидкого гелия в неделю. Приводятся предварительные результаты измерений интенсивности пучка дейтронов.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1980

Belushkina A.A. et al.

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Cryogenic Source and Ionizer
for a Beam of Polarized Deuterons

A cryogenic source and an ionizer are under development to produce a polarized deuteron beam at the synchrophasotron. A source of this type can be also applied as a jet polarized target to operate on an internal beam of the accelerator.

Deuterium dissociation in the source occurs at low temperatures. To form an atomic beam, the gas is pumped out by means of cryopumps. A superconducting sextupole magnet with a field of 1.0 T is used to separate the hyperfine structure components of atoms. The atomic beam is ionized in a Penning ionizer with a magnetic field of up to 7 T. The source operates in the pulse mode with one pulse each 5-7 s and a duration of 50 ÷ 100 ms.

The setup has been tested for 2-3 weeks without deuterium sublimation. To provide its operation, 200 litres of liquid helium were required a week. The results are presented of preliminary measurements of the deuteron beam intensity.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1980

INTRODUCTION

Cryogenic sources of polarized atoms and ions are under development at the Joint Institute for Nuclear Research, Dubna [1,2]. A source of atoms of this type can be used as a jet polarized target to operate in a main accelerator ring [3,4]. A source of ions is planned to obtain an accelerated polarized beam of deuterons at the synchrophasotron.

A cryogenic source has a series of distinctive features:

a) gas dissociation occurs at low temperatures;

b) large amounts of gas are pumped out by means of cryopumps;

c) magnetic fields are created by superconducting magnets.

A cryogenic source is compact and requires low power. This is important because the source should be installed on a special column with a voltage of 750 kV. In this paper a design of the cryogenic source and ionizer ("Polaris") is described, and results of preliminary tests are discussed.

1. DESIGN AND THE PRINCIPLE OF OPERATION OF THE SOURCE

Cryostat and vacuum system.

A general view of the source is shown in fig.1. A nozzle chamber (2), a skimmer chamber (3) and a sextupole superconducting magnet (4) are placed inside a 51 l liquid helium cryostat (1). The walls of the chambers and the sextupole magnet channel have a temperature of 4.2°K and serve as cryopanels to pump out the gas. Part of the walls is washed by liquid helium, another part is cooled due to metal thermal conductivity.

When the gas is pumped out, the temperature of the walls can be increased due to a small heat capacity and insufficient thermal conductivity of materials. This should be borne in mind because vapour pressures over the solid layers of H_2, D_2 are very strongly dependent on the temperature of the the walls. Under favourable conditions the capture of molecules takes place after the first or second collision with a wall. The process of condensation of atomic flows is less studied. The hydrogen and deuterium atoms are captured

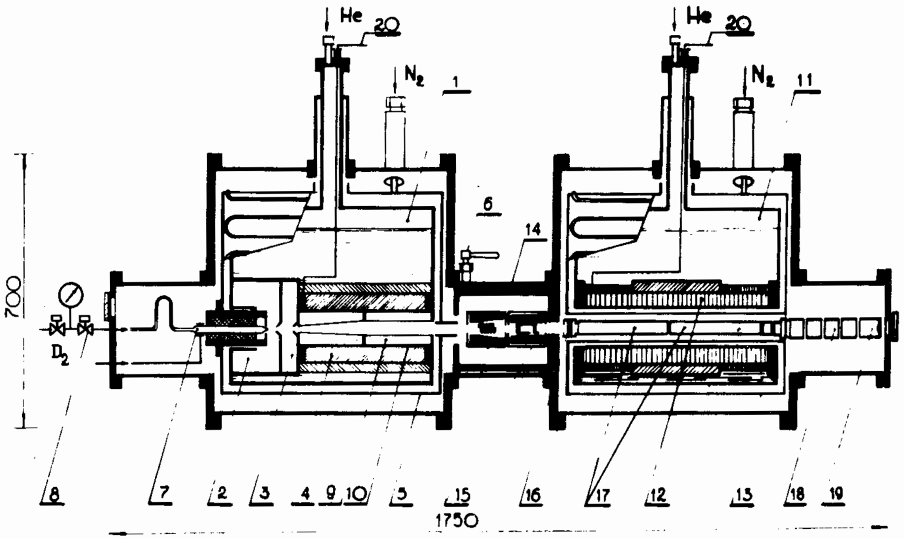

Fig.1. A general view of the source and ionizer of polarized deutrons. 1. Helium cryostat of the source. 2. Nozzle chamber of the source. 3. Skimmer chamber. 4. Superconducting sextupole magnet. 5. Nitrogen shield of the source. 6. Vacuum valve. 7. Dissociator. 8. Electromagnetic valve for deuterium supply. 9. Pole tips of the sextupole magnet. 10. Cryostat pipe. 11. Helium cryostat. 12. Superconducting solenoid. 13. Nitrogen shield of the ionizer. 14. Magnetic shields. 15. R.F. transition section of nuclear polarization. 16. Filament. 17. Anode. 18. Ion optics. 19. Ion collector. 20. Current leads.

worse than molecules at the same wall temperature[5]. In this case the speed of pumping is also dependent on the process of atom recombination, i.e., an additional number of collisions with a wall is needed.

In order to reduce the evaporation of liquid helium, the cryostat has a shield (5) cooled by liquid nitrogen. Between the source and the R.F. transition place there is a vacuum valve (6). During cooling and filling the cryostat with liquid helium, the source is pumped out by means of a 50 l/s diffusion pump.

Dissociator and system of atomic beam formation.

A pyrex glass U-shaped dissociator (7) 220 mm long is made from a pipe 13 mm in diameter. The dissociator is cooled due to the thermal conductivity of a teflon body which is in thermocontact with the nitrogen shield. The nozzle is cooled by thermocontact with the nitrogen shield as well.

To avoid the evaporation of liquid helium, the dissociator is not touched upon the nozzle chamber walls of the cryostat. To decrease the gas outflow from the nozzle chamber to the vacuum volume, a gap between the dissociator and the cryostat is minimal.

The deuterium is passed to the dissociator pulsewise through an electromagnetic valve (8) and two glass pipes 4 mm in diameter and ~270 mm in length.

The gas pressure in front of the valve is measured by a precise differential gauge and is usually equal to 4 ÷ 8 torr. R.F. power is supplied by means of a 100 MHz generator. The atomic beam is formed by the nozzle 2.2 mm in diameter, the skimmer ø 3.5 mm and a collimator ø 7 mm. The distance between the nozzle and the skimmer is 12 mm, between the skimmer and the input of the sextupole magnet is 61 mm.

Superconducting sextupole magnet.

The sextupole magnet is made so that a yoke, poles and coils are placed inside the cryostat in liquid helium and the pole tips (9) in vacuum. The poles and tips are separated by a pipe (10) of the cryostat. Part of the surface of this pipe serves as a cryopump of defocusing the component of the atomic beam. The pole tips are made from two series of sets each 140 mm long. The first set is a taper: the aperture diameter is 7 mm at the input and 12 mm at the output; the second set, a cylindrical one: ø 12 mm. The yoke and the poles are made of steel and the pole tips of 49 K2V permendur.

The coils are made of NbTi superconducting cable 0.5 mm in diameter. Each coil has 67 turns. The magnetic field on the pole tips versus current is shown in fig.2. A Hall probe is placed at a distance of 30 mm from the output of the magnet.

The magnet operates in a persistent current state.

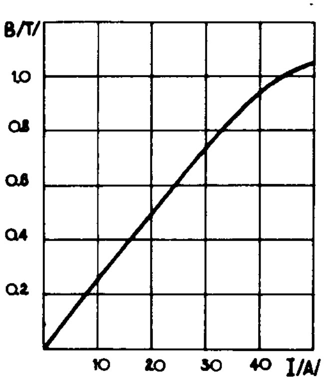

Fig.2. Magnetic field of the sextupole magnet as a function of current.

2. CRYOGENIC IONIZER

Cryostat.

Ionization of the atomic beam has been performed in a Penning ionizer (fig.1). The ionizer consists of a 46 l liquid helium cryostat (11) and a superconducting solenoid (12).

As well as the source, the ionizer cryostat is surrounded with the nitrogen shield (13). This shield has gills for gas cryopumping. An electron gun and ionizer optics are fixed in the pipe ∅ 55 mm, which is a part of the shield.

To diminish a strong magnetic field of the solenoid, the place of R.F. transitions for nuclear polarization has a magnetic shield (14).

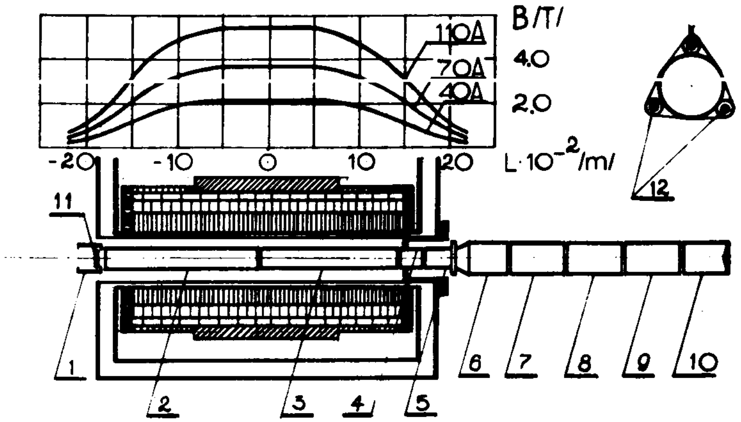

Fig.3. Distribution of the magnetic field along the solenoid axis. Typical values of potentials on the ionizer electrodes.
1. -1.0 kV; 2,3. +7 kV pulse; 4. +4.6 kV pulse;
5. +0.05 kV; 6. -0.8 kV; 7,8. -1.6 kV; 9. -1.7 kV;
10. -1.6 kV; 11. Filament -0.85 kV; 12. Framework of the electrodes.

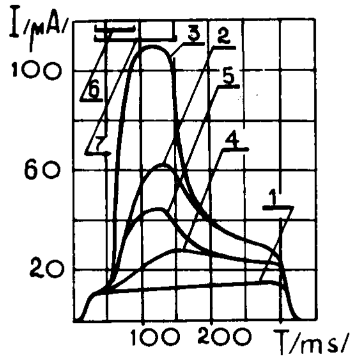

Fig.4. Signals of the ion currents registered on the ionizer collector.
1. Background ion current induced by residual gas ionization ($\sim 4\cdot 10^{-7}$ torr).
2. Current of the ionized molecular beam (the R.F. generator of the dissociator is off). The diaphragm diameter is 16 mm.
3. Ion current when the dissociator and the sextupole magnet are on.
4,5. The same as in 2,3 at a diaphragm of 3 mm.
6,7. Durations of the gas supply valve and of the R.F. generator.

During cooling and filling the cryostat with liquid helium, the ionizer is pumped out by means of a 50 l/s diffusion pump.

Superconducting solenoid.

A superconducting solenoid consists of three series windings and two correcting coils made of NbTi superconducting cable 1.1; 0.93; 0.78 mm in diameter, respectively.

The internal winding is wound on the cryostat pipe 61 mm in diameter. The length of the solenoid is 300 mm. The magnetic field along the solenoid axis is shown in fig.3. The maximal magnetic field at the centre at a current of 130 A is 6.8 T. The stored energy is 27 kj. The solenoid of the ionizer operates in a persistent current state as well as the sextupole magnet.

Electron gun and optics (fig.3).

A filament (11) and optics electrodes (1 ÷ 9) are assembled in a framework (12) that consists of three longitudinal rods isolated with quartz pipes. This design allows one to achieve a good coaxiality of the electrodes to change easily the number of electrodes and their lengths.

Electrodes (2,3,4,5) 23.5 mm in diameter are made of a stainless steel pipe. The diameter of ion electrodes (6 ÷ 10) is 36.5 mm.

The typical potentials on the electrodes at the maximal ion current are shown in fig.3.

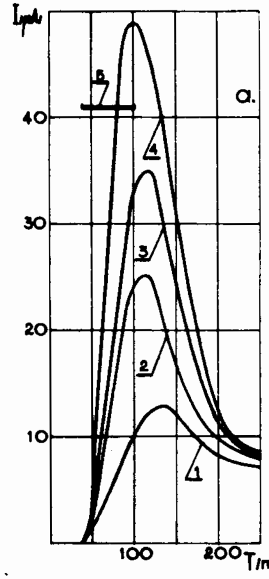
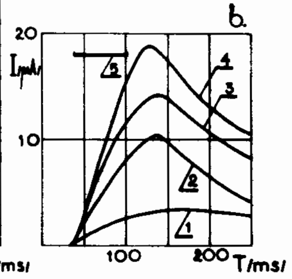

Fig.5. Molecular signals at different deuterium pressures in front of the valve. (a) the difference of the signals at the diaphragms ∅ 16 mm and ∅ 3 mm; (b) the signal at the diaphragm ∅ 3 mm. 1. 4 torr; 2. 6 torr; 3. 8 torr; 4. 10 torr; 5. Duration of the gas supply valve.

The optimal current of the solenoid for this mode is 43 A. The potentials are supplied to the filament and electrodes (1,2) pulsewise and synchronized with gas supply to the dissociator.

A hollow filament is made of a tantalum ribbon 1.2 mm wide by 0.11 mm thick and 22 mm in diameter. Electrode (1) serves as a heat radiation shield of the filament as well.

3. EXPERIMENTAL RESULTS

Some time after filling the cryostat with liquid helium and degassing the filament, the vacuum was $5 \div 6 \cdot 10^{-7}$ torr in the source and $1,5 \div 2 \cdot 10^{-7}$ torr in the ionizer. The vacuum level was likely to be determined by degassing the super-insulation of the nitrogen shield. It is possible that in the absence of the beam the vacuum in the cool channel of the sextupole magnet was better.

The pressure of deuterium in front of the valve varied within $1 \div 10$ torr, and the duration of a gas supply pulse to the dissociator was equal to 62 ms. Pulses were supplied in $5 \div 7$ s. At $P = 5.4$ torr the flow rate of deuterium was $46 \frac{\text{torr}\cdot\text{cm}^3}{\text{pulse}}$. After a gas pulse, the pressure in the ionizer was increased by $\sim 3 \cdot 10^{-8}$ torr and in the source by $\sim 3 \cdot 10^{-7}$ torr. A large increase of pressure in the source was explained by the fact that some amount of gas was supplied to the vacuum volume from the nozzle chamber through the gap

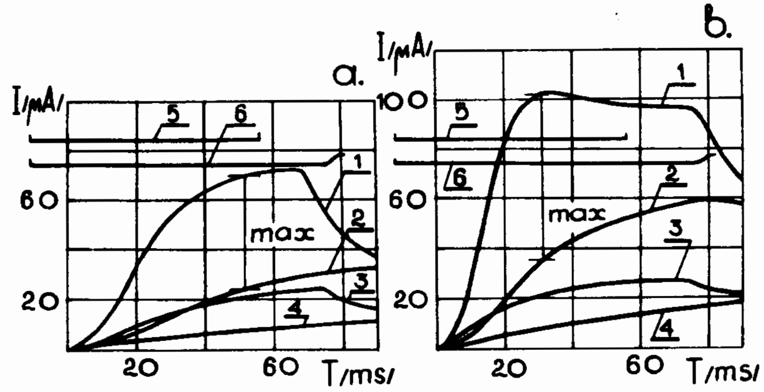

Fig.6. Variation of the ion current as the dissociator is filled with gas at the following D_2 pressures before the valve: a) 5 torr; b) 8 torr. The background current of residual gas is not shown (~ 15 mA).
1. The R.F. generator of the dissociator is on; the diaphragm diameter is 16 mm.
2. The R.F. generator is off.
3,4. The same as in 1,2 at a diaphragm of 3 mm.
5,6. Durations of the gas supply valve and of the R.F. generator.

between the cryostat and the dissociator. A part of this gas could arrive at the ionizer thus increasing a background ion current. Background and total currents could be observed closing and opening an iris diaphragm on the beam way (fig.4). The diaphragm was installed in the region for R.F. transitions at a distance of 130 mm from the output of the sextupole magnet.

Figure 5 shows the difference of the molecular signals at the diaphragms 16 mm and 3 mm in diameter and the signal observed at the diaphragm 3 mm in diameter. Figure 6 shows the value and character of variation of the ion current for the atomic beam as the dissociator is filled with gas. For a deuterium pressure of 8 torr in front of the valve the atomic effect achieves its maximum fastly and then it begins to reduce. This is likely to be due to decreasing the degree of gas dissociation. The dependence of the atomic effect on the current in the sextupole magnet is presented in fig.7. The ion current achieves its maximum at a current of 50 A

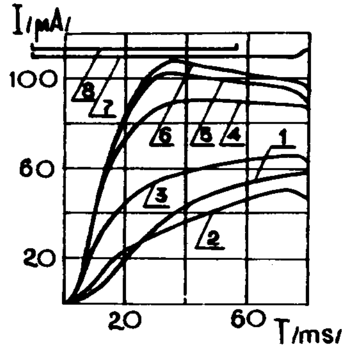

Fig.7. Atomic signal as a function of the current of the sextupole magnet at a deuterium pressure of 8 torr in front of the valve.
1. Molecular signal (the R.F. generator is off).
2. The R.F. generator is on; the sextupole magnet is off.
3,4,5,6. The same at a sextupole magnet current of 10 A, 20 A, 30 A, 50 A, respectively.
7,8. Durations of the gas supply valve and of the R.F. generator.

(3350 A·turn). When the filament is off, the ion current is not practically decreased.

CONCLUSION

The radio-frequency system of nuclear polarization did not work in preliminary tests. It will be used along with the polarimeter the assembling of which is being completed. Similarly [6], the polarimeter is based on the principle of Lamb shift using a caesium charge exchange target.

The source and ionizer were tested uninterruptedly with no sublimation over a period of 2-3 weeks.

230 litres of liquid helium were required for preliminary cooling and filling the cryostats. A subsequent filling of the cryostats was made in 4 days. The total consumption of helium for the two cryostats was equal to about 200 l a week taking into account transfer losses.

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NOTE ADDED IN PROOF

While preparing the preprint, the ion current registered on the ionizer collector (figs.4,6,7) was increased by a factor of 2. This was achieved due to increasing the potential on the electrodes 2,3 up to 9.7 kV and due to a better adjustment of the optics. The filament was off.

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